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Noise Control on Ships – Enabling Technologies

ABSTRACT

Reducing noise, in an optimal manner, has generally been relegated to the acoustical experts in the past. As shown be the Global War on Noise Workshop (2007), there has been an emphasis in the naval community to 1) improve predictive tools, 2) implement advanced control treatments and 3) understand, to a greater degree, the impact of noise on both hearing loss and the warfighters' overall performance. These technologies, if utilized on new ship designs and during retrofits of existing vessels, can enable the warfighter and crews to perform better in an improved acoustic environment. Furthermore, hearing loss impacts and their associated costs will be reduced. At the same time the usual adverse impacts of noise control treatments on weight, space, and cost, including maintainability, will be lessened as will the total cost of ownership.

The approach being undertaken by the Office of Naval Research (ONR) to reduce Noise Induced Hearing Loss (NIHL) is described in this paper. Details are provided on existing and improved acoustic modeling tools that can be applied to military programs, such as the potential noise impact of the Joint Strike Fighter (JSF) on aircraft carriers and Amphibians. Novel control treatments are highlighted including potential weight and energy savings. Proposed changes to existing programmatic/management approaches are also discussed. Bowes, et.al. (2006) showed that the bottom line is that the Return on Investment (ROI) for conducting the appropriate acoustic design rather than pay for veterans' hearing loss is on the order of 15:1 along with the added benefit of less hazardous noise exposure and better warfighter performance.

INTRODUCTION

Navy personnel work and live in noise levels that put them at risk for Noise Induced Hearing Loss (NIHL) and tinnitus. As noted on the Navy's navsafecen web site "Noise-induced hearing loss is the Fleet's number one occupational health expense". In addition, warfighter performance is often adversely impacted by operations in a high noise environment. This paper describes solution sets to reduce the Navy's risk for NIHL/tinnitus and improve the noise environment on naval vessels.

Hearing loss/tinnitus (ringing in the ears) poses a particular risk for military personnel working long hours with noisy weapon and support systems. Veteran's Administration statistics confirm the most prevalent disability claim for military veterans is hearing loss and tinnitus. In 2007 alone, Veteran compensation costs exceeded $1 B for hearing loss and tinnitus disability payments. Also in FY07, VA issued on the order of 350,000 hearing aid units. These costs continue to grow. There is a significant risk of degraded ability to hear communications quickly and accurately; reduced auditory cues/awareness of approaching hazards; and the personal-human awareness of trying to function at work and in normal life with a hearing impairment.

This paper addresses noise issues through:

- Use of engineering analysis tools to determine optimal control solutions
- Noise and vibration control mitigation strategies, including the development of novel control treatments
- Analysis of, or advances in, environment- or job-specific personal protective equipment (PPE) and impact in reducing noise exposure
- Training and education to improve awareness of tools and appropriate methods to reduce noise exposure and shipboard noise

An overview of the NIHL approach is outlined in Figure 1. These planned management and engineering approaches will reduce and minimize the hearing exposure levels of crews. In addition to the personal toll on health and

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fitness, the real cost associated with neglecting acoustic problems, in terms of hearing loss compensation and lost productivity, will be

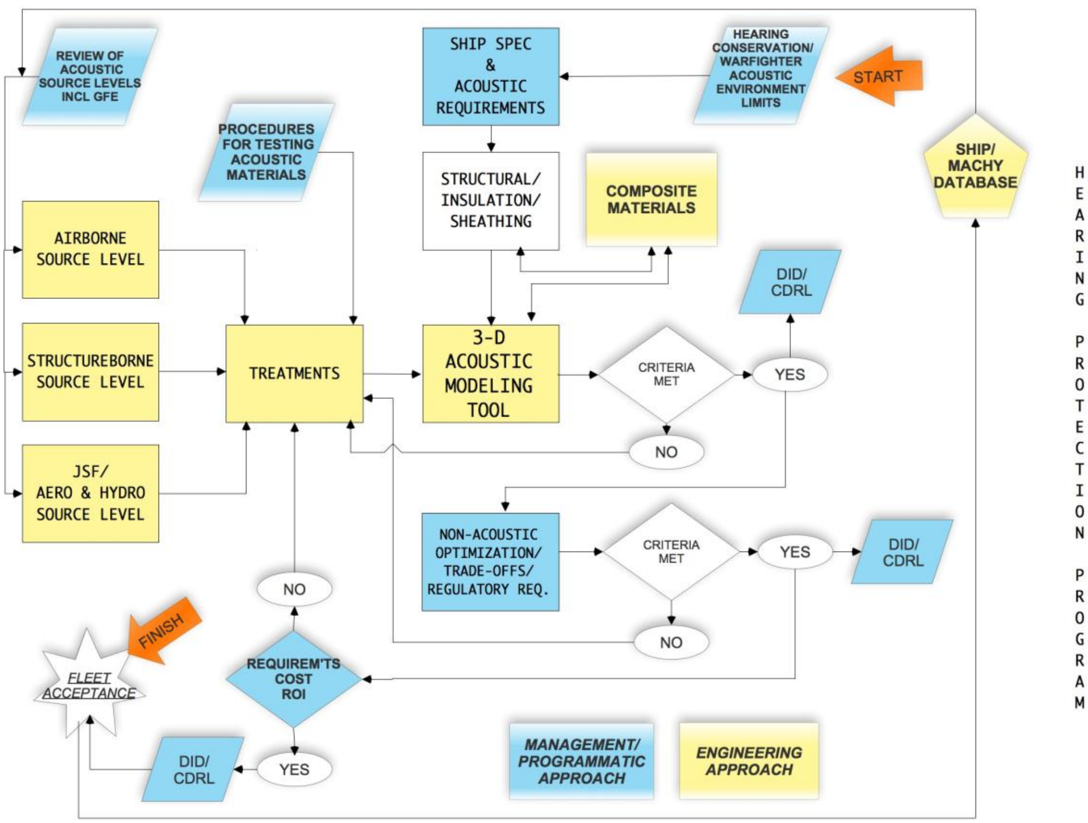

Figure 1. Management and Engineering Approach to NIHL program

reduced.

ACOUSTICAL ENGINEERING ANALYSIS TOOLS

There are generally two-noise analysis tools used on US Navy vessels. One method is the 'cook-book' method laid by Fischer, Burroughs & Nelson (1983) in a SNAME document. The other developed by Fischer, Boroditsky & Spence (2004) is a 3-D CAD type approach developed as part of an USN sponsored SBIR 98-092. The former is a useful primer on shipboard noise control; the later is a universal and a practical noise modeling and mitigation tool. Spence, et.al (2006) shows this approch to be accurate on many different marine constructions and for a variety of propulsion machinery. The objective of the SBIR was to develop a general use software tool that would allow the naval community to evaluate the noise at any time from concept design through service life extensions.

As outlined in Figure 2, these tools allow the "user" to identify the frequency dependent - critical noise sources, transmission paths, and receiver characteristics that control the noise environment under the various vessel operation conditions. The output will identify areas with noise excesses and the causes of these excesses. The "user" up to this point can be any marine engineer or naval architect who knows and understands the basic construction of a marine vessel; being able to read and understand drawings detailing general arrangements, machinery, structures, insulation, and sheathing and input this information into the acoustic CAD program. The case study provided later in this paper illustrates this approach.

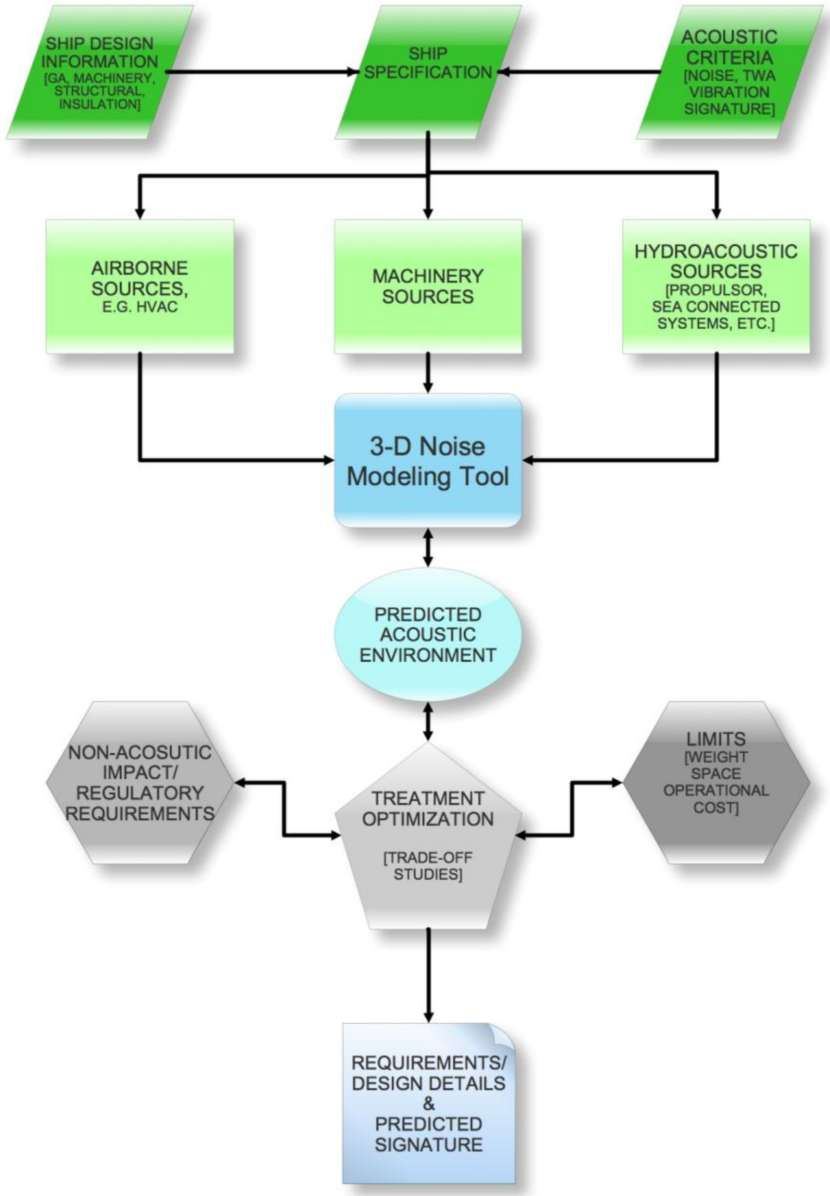

Figure 2. Three-D Computer Aided Design (CAD) acoustic modeling process

Once the noise problem is fully identified and understood by exercising the CAD model, then optimal noise control strategies can be implemented. The optimal solution not only addresses the noise environment but needs to consider the impact of regulatory material requirements; cost of material and their installation and maintenance; space required for the treatments; and weight impact. The biggest advantage of a 3-D CAD approach is that the model can be quickly developed and 'trade-off' studies implemented so as to enhance the overall noise evaluation and control in a timely manner. Again, a 'user' can try to implement various control strategies; however, a person with an

acoustic background is more likely to effectively implement an optimal solution.

The CAD program predicts the octave band and A-weighted received noise levels in compartments of interest and provides useful information on the sources, transmission paths and receiver characteristics that can control the vessel's noise environment. It allows for quick iterative designs with absorptive, high transmission loss, isolation mounts, and/or damping treatments. The acoustic performance of novel treatments can be 'user' entered.

The performance of any acoustic material ultimately depends on multiple parameters, all of which must be considered in order to determine the overall impact of the material on the noise environment. These parameters consider the material's impact with respect to absorption, airborne transmission loss, damping, radiation efficiency and acceptance (vibration response to incident airborne noise). For instance, improving the absorption alone may not be beneficial if the material provides low airborne transmission loss. Numerous material properties, addressing the five parameters above, are included in the CAD software or can be added by the user.

The current effort will improve the existing software by:

i. incorporating the capability to compute time weighted noise (TWA) exposures for hearing loss evaluations

ii allowing one to perform trade-off studies on engineering solutions versus impact on hearing loss compensation and treatment cost/space/weight requirements

iii. developing models capable of addressing external acoustic sources like Joint Strike Fighter (JSF), considering jet impinging on deck and propagation of energy from excitation point on deck – for both CVN and amphibians.

Via this approach, government audiologist can access the TWA calculations to determine the crewmembers most likely to be exposed to hazardous noise levels. Once identified, their yearly hearing tests can then be closely monitored and become part of the Navy's Noise Exposure Assessment Tool (NEAT).

NOISE MITIGATION STRATEGIES

There are two basic mitigation strategies – applying engineering controls or administrative controls and personnel protection. The preferred solution is engineering controls. With a robust system engineering approach this is a cost effective method. Administrative controls such as removing a person from a high noise environment places additional manpower demands for noise exposure crew rotation. The common solution tends to be providing hearing protection (earplugs and earmuffs). A recent Navy study by Bjorn (2006) demonstrated a very low compliance with the proper use of hearing protection. As noted by Yankaskas (2009) the effectiveness of hearing protection, part of the management of exposure approach, can be highly effective given new deep insertion plug and other recent advances. Plug and muff are absolutely necessary in high noise environments in order to reduce crew hazardous noise exposure. Noise levels in a compartment in excess of 84 dB(A) are deemed Noise Hazardous, requiring single hearing protection upon entering. Compartments with noise levels in excess of 104 dB(A) require double hearing protection – ear plug and ear muffs.

However, a recent study has shown that the Return on Investment is approximately 15:1 where engineering controls are applied versus the cost of hearing compensation paid to Navy veterans [9]. Generally specific costs associated with hearing loss compensations have not been consistently considered in ship acquisition program reviews. Part of the ONR NIHL management strategy consists of :

- Identifying improvements to the documents currently used in ship specifications
- Developing new requirements documents needed to further define the management process needed to successfully carry out a total Noise Control Program

- Creating searchable acoustic and treatment effectiveness databases and methods to keep track of acoustic source levels and ship noise surveys
- Categorizing GFE acoustic source levels that materially affect the noise in critical compartments
- Outlining and presenting educational programs needed for SDM's, SUPSHIPS, INSURV, and others in order to carry out a complete noise effort from specification development to compliance and acceptance.

With these approaches and tools, ship acquisition program managers (PM) will have the technology needed to evaluate the return on investment (ROI) over the life of the ship achieved by proper inclusion of engineering controls for noise into the ship design. For most current ship programs engineering controls for noise are not consistently optimized, leading to unnecessary costs.

The tools and approaches being developed as part of the NIHL program can be used by the marine community to (1) estimate the ROI achieved by implementing engineering controls for noise, (2) reduce the exposure of ship personnel to hazardous noise, and (3) optimize the noise control measures implemented during design. This new technology will be suitable for use by PM's on new ship programs at the preliminary design stage and during detail design. It will also be suitable for use on overhauls and SLEPs.

This top-down systems approach can be used to develop the noise and vibration sections of a ship specification, 073 and 095-073 and their associated deliverables (DID's). The modeling can assist in determining the acoustic environment and optimal noise and vibration control approaches to incorporate in the specification or to provide to bidders to assist them in costing the noise control for a particular class of vessels.

In addition, updated/revised documents are needed to further define the management process. This includes how to develop and implement a successful Noise Control Program; develop searchable acoustic databases and methods to keep track of acoustic source levels and ship noise surveys; identify methods to assess GFE acoustic source levels that materially affect the noise in critical compartments; and outline needed educational programs for SDM's, SUPSHIPS, INSURV, and others in order to carry out a complete noise effort from specification development to compliance and acceptance. In order to effectively implement any Noise Control Program for a class of naval vessel it is necessary to have educated engineers, inspectors and testers. These personnel need a basic understanding Navy noise criteria[1] and of the salient parameters controlling shipboard noise. A Noise Control Plan needs to provide an organized approach describing how acoustic performance requirements are reviewed, assessed and translated into design, construction and testing of the ship.

The major elements of the Noise Control Plan (NCP) are closely interrelated. Development of the engineering package is an iterative process that continues throughout the design and construction program. The total plan should consist of the following elements:

- *Plan review and management:* This element provides procedures to monitor the status and performance of the NCP. Procedures need to be defined and schedules established to oversee the design, construction, and testing phases. Methods to handle engineering changes need to be provided.
- *Acoustic goals:* This element establishes acoustic goals and the ship operating conditions at which these goals should be met (as defined in Section 073 of a typical ship specification).
- *Performance control and review procedures:* This element details the review procedure for implementing the NCP. Furthermore, it defines the technical approach for estimating the habitability noise and vibration levels

[1] Shipboard Habitability Design Criteria Manual, T9640-AB-DDt-010/Hab; OPNAV Inst. 9640.1A; OPNAV Inst. 5100-19D, 19E and 23G; and Mil-Std 1474D.

for a given ship operating condition and for developing methods for reducing the noise or vibration, if a noise excess is predicted.

- *Quality assurance:* This element consists of drawing reviews and construction inspections needed to ensure correct implementation and installation of treatments onboard the vessel.
- *Acoustic trials:* This element is used to prove that the vessel operates satisfactorily through a program of dockside and underway acoustic trials. If necessary, diagnostic tests are included to assist in finding the source and/or path contributing to any problem. Problem resolution, in the form of corrective actions, needs to be well defined to avoid obtaining waivers that defeat the primary purpose of controlling the noise in an optimal fashion.

NOVEL TREATMENTS

Any treatment that combines noise reduction along with other non-acoustic features such as anti-sweat, thermal or fire obviously has significant advantages over a single purpose treatment. In recent years, significant strides have vastly improved the potential for spray-on treatments that will help abate airborne noise on Surface Ships. The optimal insulation will provide high acoustic absorption, airborne transmission loss, and structural damping along with the requisite thermal/fire/condensation protection. SBIR sponsored research is investigating how these products can be combined for maximum results. The conclusion will yield a method of blending and installation that will reduce handling, weight and installation costs.

As noted previously, these products are being tested for their impact on absorption, acoustic radiation, acceptance, damping and airborne transmission loss characteristics using a standard 8’ x 8’ x ¼” thick bulkhead built in accordance with ASTM E-90. These products are water soluble and spray applied offering many advantages. The coatings will take up less space than conventional insulation, adhere to the surface that they treat or protect, cover and conform more completely, are easily repairable and are light-weight in nature than some of the standard treatments such as Navy standard damping tile. The Mil-Std damping tile is also becoming a scare commodity. Because this system adheres to the surface being treated, it significantly reduces corrosion under insulation. Unlike conventional mass insulations, they will not harbor mildew, mold, pathogens, rodents or insects between the insulation and the ships surface.

Spray-on damping treatments have been applied and shown to be effective on naval vessels, SEA FIGHTER, and commercial vessels. Figure 3 shows that a bulkhead treated with a spray-on damping material radiates less effectively than one treated with Navy Standard Damping tile.

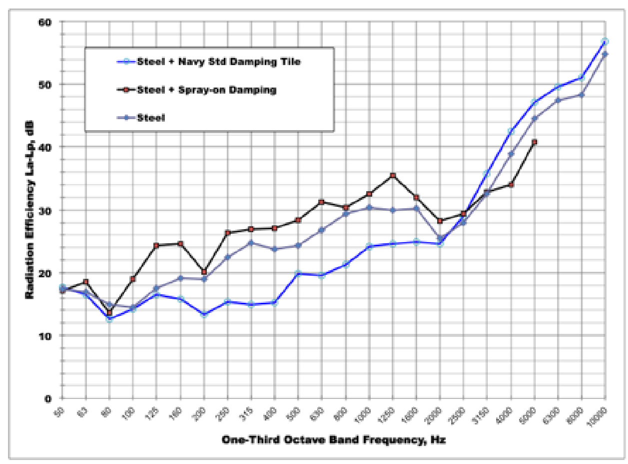

Figure 3. Impact of damping on radiation efficiency; (Higher value = less radiation for a given vibration level)

Some noise control treatments or approaches can have significant side-benefits. As part of this effort it has been found that the noise from the intake/exhausts for gas turbine can be reduced. Computational Fluid Dynamic (CFD) analyses used to reduce the flow-induced noise also allows for a significant fuel savings on each gas turbine. The estimated fuel savings is over $300k per gas turbine per annum. The impact of proposed flow changes is shown in Figure 4. An

added benefit of the proposed changes is a reduction in CO_2.

Case History:

A partial acoustical model of CVN-72, Figure 5, was developed to check the ability of a 3-D acoustic software tool to analyze noise from flight operations. This area includes the Chaplain block, Alternative Training Room, Crew Library and other adjacent rooms on the Gallery Deck and one deck lower. The source airborne noise levels above the flight deck and flight deck vibration levels were based on measured source data taken during F-18 flight operations. The four red blocks represent these sources. The goal of this modeling is to find physical reasons for excessive noise levels in compartments under the Gallery Deck: to determine the most active structural elements, physical components (structureborne or airborne), frequency range controlling overall level and other pertinent parameters.

The overall A-weighted level of this spectrum is approximately100 dB(A), which is close to the measured 103 dB(A) value for the Chaplain office during F-18 launch through catapult L3. Table 1 shows that both airborne and structureborne components prevail and that the frequency range between 125 and 2000 Hz controls overall level. Figure 6 shows that the predicted vibration levels on the deck in the Chaplain Office are well represented by the model.

As a next step for diagnostic, one can investigate the radiated noise contribution of each surface of the room to the overall noise level in the room. Table 2 shows octave band noise levels predicted to be radiated from each surface in the Chaplain 2 compartment. The bold highlight the element and frequency range over which that element controls the predicted radiation. At different frequencies, different elements control the received level, indicating that treating only one surface would not supply sufficient noise abatement.

Flight noise studied with a "simple" 3-D model shows such modeling will be an effective tool for noise control optimization for noise sensitive spaces under the flight deck. This approach shows that if source data are reliable then the noise prediction results should be accurate and realistic treatment trade-off studies can be conducted. The effect of different types of treatment and their optimization in terms of performance and their impact on weight, space and cost can be fully evaluated.

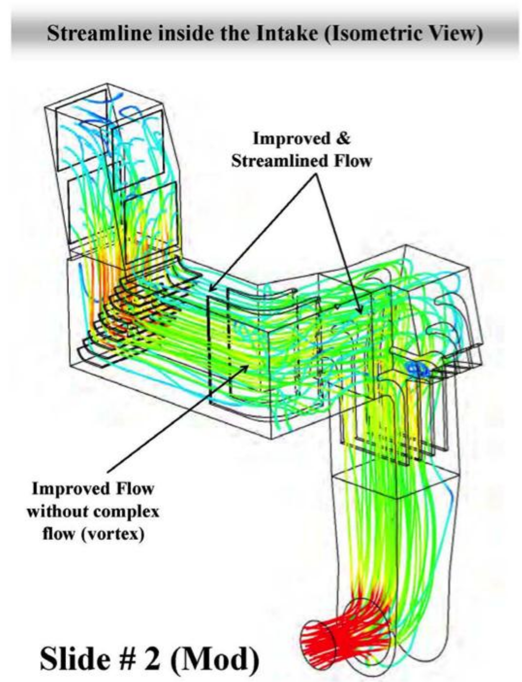

Figure 4. Improved flow based on CFD analysis of GT intake

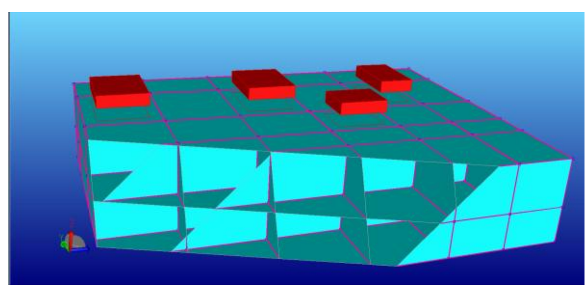

Figure 5. Three-D acoustic model of a section of the CVN under consideration.

CONCLUSION

The Navy, through its NIHL program, is addressing and improving methods and techniques that can and should be used to reduce hazardous noise exposure and improve warfighter performance. The objective is to educate the community – from the top down -

Table 1: Predicted noise for Chaplain 2 – due to F-18 launch (A-weighted)

Transmission Path									
Octave Band Freq., Hz	31.5	63	125	250	500	1000	2000	4000	8000
Airborne - AB	55	71	81	**96**	81	73	56	47	35
Structureborne -SB	63	79	87	**93**	87	86	89	82	71
Secondary - SSB	53	68	77	**85**	82	80	74	62	43
Total	64	80	89	**98**	89	87	89	82	71

In this table the following notations are used: AB – airborne noise transmitted through flight deck, SB – structureborne noise, excited by mechanical impact, SSB- structureborne noise, excited by airborne noise.

Table 2: Predicted noise by structural component – Chaplain Compartment – F18 Launch

Octave Band Freq, Hz.	31.5	63	125	250	500	1000	2000	4000	8000	dB(A)
Element										
Flight Deck	**102**	**105**	**103**	**101**	**86**	73	61	53	45	94
Outboard BHD	87	89	87	88	82	79	80	73	64	86
Inboard BHD	88	90	88	89	83	80	82	75	66	88
03 Level deck	88	91	89	90	83	**81**	**83**	**76**	66	88
Aft BHD	88	91	89	90	83	80	82	75	66	88
Forward BHD	86	89	86	87	80	77	78	71	61	85

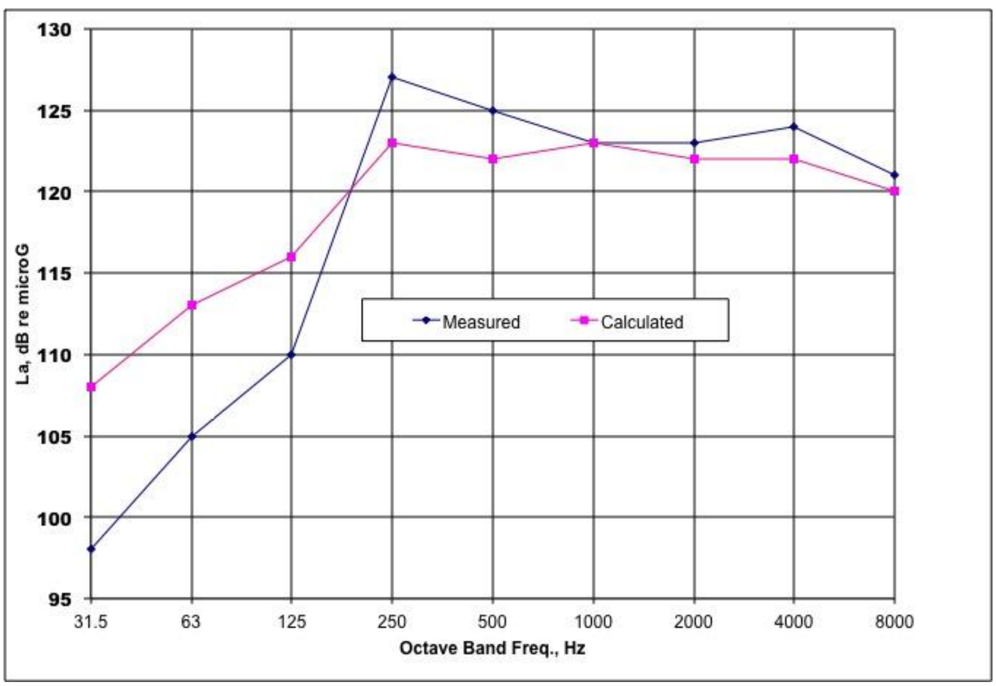

Figure 6. Measured v. predicted vibration on deck in Chaplain Office

and provide them with the management and engineering tools to address and redress noise issues in an effective manner.

As Sun Tzu said, "Strategy without tactics is the slowest route to victory. Tactics without strategy is the noise before defeat." To avoid the defeat and noise lets put the strategy and tactics into play.

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